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EFFECTS OF DDT ON SALTMARSH WILDLIFE 1949

SPECIAL SCIENTIFIC REPORT: WILDLIFE No.10

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UNITED STATES DEPARTMENT OF THE INTERIOR, Oscar L. Chapman, Secretary
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Special Scientific Report - Wildlife

No. 10

EFFECTS OF DDT ON SALTMARSH WILDLIFE: 1949

by

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Biologists

1951

CONTENTS

	Page
Introduction	1
Spraying Program	1
Species Studied	3
Nature of the Marsh	3
Tidal Movements	4
Effects of Spraying on Vertebrates	5
Birds	5
Fishes	8
Effects of Spraying on Invertebrates	12
Insects	12
Blue Crabs	14
Fiddler Crabs	17
Other Invertebrates	20
Summary	23

ACKNOWLEDGMENT

Note: The biological phases of this study were planned under the direction of Joseph P. Linduska, formerly head of the Wildlife-Insecticides project and now Assistant Chief of the Branch of Wildlife Research, and Arnold L. Nelson, Director of the Patuxent Research Refuge. The cooperation of numerous individuals and agencies made this project possible, particularly that of Henry E. Whitley, manager of the Brigantine National Wildlife Refuge, Robert T. Mitchell, and others of the Patuxent Research Refuge staff who assisted in many ways in the preparation of this report. Assistance in various phases of the field studies was given by Emerson Hibbard, Robert C. Van Etten, and William C. Good of the Patuxent Research Refuge.

This publication was reviewed and edited by Dr. A. C. Martin.

INTRODUCTION

DDT has been used extensively for mosquito abatement in saltmarsh areas in recent years. As a result there have been numerous reports of possible hazards and of actual harm to wildlife and fish populations. Until now, however, there has been almost no study of the broad consequences of these mosquito control operations.

This report covers the first season's investigations of a proposed two- or three-year cooperative study on the biological consequences of DDT sprayings on a salt marsh at the Brigantine National Wildlife Refuge, Oceanville, New Jersey.

Purposes of the study were to ascertain effects on fish and wildlife of sprayings comparable to those applied to salt marshes for control of mosquito larvae and to look for methods of allaying or possibly eliminating damage to the more important forms of life. To a considerable degree, investigations in 1949 were exploratory and were directed toward the search for suitable methods to determine DDT effects upon marshland wildlife populations.

Spraying Program

Plans for this study resulted from cooperative arrangements with several federal and state agencies. The Bureau of Entomology and Plant Quarantine of the U. S. Department of Agriculture supplied the insecticide and the plane for aerial application. The New Jersey Agricultural Experiment Station investigated effects upon insect pests of the area, particularly the saltmarsh mosquitoes and the greenhead fly. Personnel of the New Jersey Fish and Game Division gave active assistance during several phases of the study.

Reasons for choosing the Brigantine Refuge site were threefold: (1) it was considered typical of marsh areas commonly subjected to spraying, (2) it has representative populations of saltmarsh wildlife and the organisms upon which they depend for food, and (3) studies could be conducted on it without interference to or from other activities or objectives.

Four study areas of 50 to 100 acres were selected to be treated by airplane at rates of 1.6, 0.8, 0.4, and 0.2 pounds of DDT per acre respectively.[1/] Each area was sprayed twice, the first application occurring between August 17 and 19, mostly at high tide, and the second on September 15 and 16 at low water.

1/ Hereafter, these plots or dosages are designated as the 1.6, 0.8, 0.4, and 0.2 plots or dosages.

The spray used was Shell ACX-331 containing 10.75% DDT in light fuel oil with an auxiliary solvent. The two lower dosages (0.2 and 0.4) are within the range normally utilized in larval control while the two higher rates cover a dosage range occasionally used for pre-emergence treatment. In typical control operations the interval between sprayings varies from a period of several weeks to more than a month, depending upon breeding conditions, but in this study, the amount of time required for pre- and post-spray investigations made it impossible to schedule treatments at intervals of less than one month.

Each of the units treated in the first spraying was approximately 100 acres with the exception of the one treated with the 1.6 dosage which was 50 acres (see Fig. 1). Before the second spraying, the 100-acre units were reduced to 90 acres for operational reasons. In addition, the boundaries of the two higher dosage areas were shifted to provide a combination of spray treatments in relation to time and number of application. Thus parts of each of the plots were sprayed only once and other parts twice. Study areas selected were representative portions of the marsh, including large and small creeks, ditches and ponds. Their large size helped to reduce effects of local differences in habitat and of immigration by unaffected animals after spraying.

Studies on population fluctuations of marsh organisms were also made in nearby unsprayed habitats. These check areas included untreated portions of the marsh that were comparable to the test areas and that were well beyond the range of drift or drainage from the spray plots.

The plane used for insecticide application was an N3N-3 single-engined biplane, equipped with a spray rig having an effective swath width of 90 feet at an altitude of 25 feet. Two sets of nozzles were employed. The set used on the 0.8 and 1.6 areas discharged one gallon per acre when the plane was traveling at an average speed of 85 miles per hour. The other set was used when spraying the 0.2 and 0.4 areas and released one quart of insecticide per acre. On the 0.2 and 0.8 areas the plane made runs at 90-foot intervals while where the application was greater, the intervals were reduced to 45 feet. Flight lines were marked by men with flags at each end of the plots.

The two higher dosage areas were treated in the afternoon of August 17; the 0.4 area in the afternoon of August 18; and the 0.2 area during the morning of August 19. The difference between tide stage at the time of spraying on the 0.2 area compared to that on the other plots introduced a variable, as did the fact that a light drizzle on August 18 helped to wash off spray from the high dosage areas.

The second treatment was started in the early morning of September 15. The 1.6, 0.8, and 0.4 areas and a quarter of the 0.2 area were sprayed before unfavorable weather intervened. Operations were resumed at low tide in the evening, at which time an additional half plot was treated. Spraying was finally completed in mid-morning of the 16th.

Unfortunately, the nozzles used on the two lower dosage areas during this second application apparently were not calibrated correctly. From a calculation of the insecticide used on the 0.4 area, it was determined that the discharge rate was approximately one quarter greater than desired. This gave a dosage of about 0.53 pounds per acre instead of 0.4, and 0.26 pounds per acre instead of 0.2. By shutting off two of the eight nozzles, a nearly correct dosage was obtained for the remaining three quarters of the 0.2 area. These and other variables have been considered in evaluating the relative effects of the spray on the study plots.

One other factor must also be considered in comparing the effects of DDT. The method used, while providing the desired dosages of DDT, resulted in a great difference in the amount of oil applied to each area. For example, the 1.6 area received 8 times as much oil per acre as did the 0.2 area, or approximately twice as much as would be applied in most larval control. In view of the toxic properties of oil to certain forms of life, it is recognized that this in itself could cause an unduly high mortality in the areas of greater dosage. At the same time, it should be borne in mind that increased dosages of DDT in operational work frequently are accomplished by applying a greater quantity of a standard mixture. While the procedure used complicated direct comparisons of the effects of different amounts of DDT, it had the important advantage of approximating operating conditions.

Species Studied

Special attention was focused on the invertebrates of the marsh. These essential links in the food chains of wildlife usually occur in larger numbers than do vertebrates and the majority of them are more readily susceptible to DDT poisoning. Decimation of invertebrate populations by DDT could conceivably result in serious detriment to some valuable species of marsh wildlife. The blue crab is the only local invertebrate with appreciable direct economic importance.

Though the primary focus of population studies in relation to sprayings was on the lower animals, considerable attention was also given to fishes and birds, some of which have significant value for sport or commercial purposes.

Nature of the Marsh

Because of an extensive system of ditching, the study area is better drained than comparable unaltered marshlands. However, despite ditches, the meandering creek channels with which they connect, and the draining effect of ebb tide, there are numerous places where standing water is likely to be found. In this report, these water bodies are called ponds or pools; the term tide pool being used also for those directly influenced by tides. Ponds or pools of the marsh vary in size as well as in degree of permanence. Generally, they are shallow, ranging in depth from a few inches to a foot or more.

The salinity of marsh water depends largely upon the tides, but is also influenced by fresh water flow from upland sources and by rainfall. It ranges from nearly or greater than sea-water strength to varying degrees of brackishness.

In the study area, as in much of the Atlantic Coast marshland, saltmarsh cordgrass (Spartina alterniflora) is the prevailing plant. It is particularly dominant throughout the extensive outer zone bordering the bay. Along the margins of creeks and ditches it attains a taller, more luxuriant growth. An inner, slightly higher and better-drained zone is covered largely by saltmeadow cordgrass (Spartina patens), along with smaller amounts of saltgrass (Distichlis spicata) and blackrush (Juncus gerardi). On creek banks and other elevated places, marshelder (Iva frutescens) and groundselbush (Baccharis halimifolia) are likely to be found. Saltwort (Salicornia spp.) occurs on flats that are subject to intermittent shallow inundation; and the excellent duck-food plant, widgeongrass (Ruppia maritima) grows in some of the large clear ponds. Various algae are also present in some ponds.

Tidal Movements

The profound influence of tides upon the organisms inhabiting the salt marsh was of importance in population studies. Rivers and creeks subject to typical tidal forces alternately flow and ebb twice in each lunar day, the average period between successive high and low tides being somewhat over 6 hours. In the bays adjoining the study area, the mean range between high and low water is about 3.6 feet while near the time of full and new moon this increases to a maximum of 4.4 feet. Species such as fish, shrimp, blue crab, etc. move with the tide and their numbers in the marsh rise and fall accordingly.

Tidal movement is likewise an important factor in determining the severity of mortality from DDT. Spraying at low tide results in less dilution of DDT. Although the numbers of animals subjected to the hazard of poisoning are at a minimum at this time, they are crowded into a smaller volume of water where the chances for contact are greater. At high tide the reverse situation exists. The possibilities of contact with an individual animal are lessened but at the same time more animals are present within the sprayed area. It would appear that spray applied at high tide would be washed out more quickly than a low-tide treatment. In view of these facts, the timing of DDT applications in relation to tides becomes an important consideration in determining the extent of harm resulting from marsh spraying.

EFFECTS OF SPRAYING ON VERTEBRATES

Birds

Species and Ecology

Relatively few species of birds in this region confine their nesting to the coastal salt marshes. However, those that do are present in large numbers. Resident marsh species within or near the study area numbered only four: the clapper rail (Rallus longirostris), laughing gull (Larus atricilla), sharp-tailed sparrow (Ammospiza caudacuta) and seaside sparrow (Ammospiza maritima). A second group uses the salt marsh as only a part of their nesting habitat. In or near the study plots these included the black duck (Anas rubripes), long-billed marsh wren (Telmatodytes palustris) and red-wing (Agelaius phoeniceus).

In addition to species which nest in the salt marsh, others come here to feed during the summer months. Common members of this group are the great blue heron (Ardea herodias), American egret (Casmerodius albus), snowy egret (Leucophoyx thula), little blue heron (Florida caerulea), green heron (Butorides virescens), black-crowned night heron (Nycticorax nycticorax), marsh hawk (Circus cyaneus), fish crow (Corvus ossifragus), tree swallow (Iridoprocne bicolor), and barn swallow (Hirundo rustica). Later in the year, numerous migrants, particularly shorebirds and waterfowl, frequent the salt marsh.

Methods of Study

The effects of spraying upon bird life of the marsh were determined by two procedures: (1) general observations in all study areas and (2) strip counts in the two higher dosage areas (1.6 and 0.8).

General Observations

After the first spraying there was a decided decrease in the use of the 1.6 and 0.8 areas by tree swallows. The birds confined their activities more to untreated areas, seemingly in correlation with reduction of flying insects over the sprayed portions of the marsh. The 0.4 and 0.2 areas had small swallow populations before spraying and no changes were observed there following treatment. Prior to the September spraying, swallows were again common in the 1.6 and 0.8 areas and remained so afterwards.

Before the first spraying, laughing gulls were fairly common over the 1.6 area and roosted regularly part of the day on a few favored beds of saltmeadow cordgrass. Four counts revealed an average of 61 birds frequenting one bed in this area. On the morning following treatment, several hundred gulls and a few common terns (Sterna hirundo) were observed at low tide feeding on dead fish in the larger creeks and calling excitedly. This behavior attracted additional gulls which were seen flying to the area. Undoubtedly some birds came from a distance as these were the first common

terns seen within the marsh. The nearest point where they had been observed previously was along the main portion of the bay, about 3/4 of a mile distant. Thereafter no large groups of gulls were seen although scattered individuals were observed flying over the area as was the case before spraying. In like manner, the roosting spot was deserted except on one occasion five days later when a group of 70 was noted. Presumably the majority had left to feed in other parts of the marsh.

Gulls were much less numerous on the three lower dosage areas before spraying, and they remained so afterwards.

Effects on gulls from the second spraying were similar to the first. Laughing and herring gulls (Larus argentatus) were noted feeding on dead fish and blue crabs. On this occasion they were observed in the 0.8 and 0.4 areas as well as in the high dosage unit.

As a test of whether gulls were affected by eating blue crabs that had died or were dying from DDT, crabs recovered from the creeks and ditches of the 0.8 area after the second spraying were dumped on a dyke close to the gulls' roosting spots. Although many of these were eaten, no resulting illness or mortality of gulls was evident.

Observations on the feeding habits of herons and egrets after spraying indicated that they took little, if any, of the dead fish. In several instances birds were noted feeding in shallow ponds with dead fish floating nearby. In every case they took live fish. No changes were noted in the number of herons after treatment of the areas.

There were no indications of harm resulting to clapper rails although direct observation of these birds is difficult due to their secretive habits. Surveys after sprayings revealed no dead rails. Rails consumed many dead fiddler crabs as evidenced by the increased numbers of large claws of male crabs, commonly discarded by rails.

A pair of long-billed marsh wrens in the 1.6 plot were observed to successfully rear five young. The nestlings were about a week old at the time of spraying and no abnormal behavior was noted then or thereafter. Two of the young collected four days after leaving the nest had well-filled gizzards as did several adult birds.

Three young sharp-tailed sparrows that fledged in the 0.8 tract the day before spraying were likewise observed for a week afterwards and appeared to act in a normal manner. Similar evidence was obtained for a seaside sparrow, with no indications that the bird or its young were affected.

Strip Counts

Since the breeding season was largely past at the time of the August spraying, the mapping of nesting territories to determine bird populations in the marsh could not be employed. Instead a strip count method was used. Strip count routes were established in the two higher dosage plots: one route about 1.1 miles long was laid out in the 1.6 area

and a second, 0.8 mile long, in the 0.8 area. These included transects through both tall and short grass habitats. Counting trips were made on each of the two areas in the early morning and late afternoon of the two days preceding spraying. Following spraying, trips were again taken in the late afternoons between the fourth and eighth days. It was reasoned that the greatest effect of reduced insect food supplies might be evident during this period.

The counting procedure involved walking the routes and noting the individuals flushed, seen, or heard. The effective recording range on either side of the strip was considered to be about 75 feet in the case of small birds and 300 feet for larger or more conspicuous ones. Swallows were so numerous that only those flying in front of the observer within a distance of 150 feet were counted. The strip count method did not prove to be practicable for rails. A few were heard and seen each trip and only the higher of the sight or sound records was listed. In all cases, strip counts were limited to birds regarded as residents or regular visitors to the marsh.

Before spraying, the number of resident birds per trip on the 1.6 area averaged 27-3/4 compared with 26-3/4 after spraying, a decrease of 4%. Comparable figures for resident birds on the 0.8 area were 31 and 34-1/4, an increase of 10%. It appears, therefore, that DDT application had no significant effect on the resident bird population on these two areas during an eight-day period following spraying.

Visitant birds feeding within the 1.6 area averaged 54-3/4 per trip before the spray and 25-1/2 afterwards, a decrease of 53%. However, the swallows accounted for most (93%) of this decrease since their numbers diminished 55% while other species decreased 36%. The decline in the number of laughing gulls following spraying was responsible for the greater part of the remainder of decrease. In the 0.8 area, also, the number of visitants after spraying fell off sharply, declining from 30-1/4 to 17, or 44%. As in the 1.6 area swallows accounted for the greater part of this reduction.

Fishes

Species and Ecology

Of the fishes found in ponds, ditches and creeks of the salt marsh studied, killifish predominated. Fundulus heteroclitus was particularly plentiful but F. majalis was also present. These killifishes were used as primary indicators of DDT effect. They ranged from less than 1 inch to about 6 inches in length but individuals more than 4 inches long were uncommon except toward the mouths of creeks. The killifish, Cyprinodon variegatus, was common in the tide pools while the silverside minnow, Menidia menidia, was common in creeks but rare in standing waters. An indication of the kinds and numbers of fishes in various locations of the marsh is given in the following record of preliminary seinings:

JUNE 25 DITCH; Haul With Minnow Seine
- 42 Killifish Fundulus heteroclitus and Fundulus majalis 1/2" - 3-3/4"

JUNE 25 TIDE POOL; Haul With Minnow Seine
- 538 Killifish F. heteroclitus and F. majalis 5/8" - 2-1/2"
- 27 Killifish Cyprinodon variegatus 3/4" - 2"

JULY 6 TIDE POOL; Haul With Minnow Seine
- 510 Killifish F. heteroclitus and F. majalis 3/4" - 2-5/8"
- 30 Killifish Cyprinodon variegatus 5/8" - 2"

JULY 13 TIDE POOL; Haul With Minnow Seine
- 158 Killifish F. heteroclitus and F. majalis 1/2" - 2-3/4"
- 10 Killifish Cyprinodon variegatus 5/8" - 1-1/4"

JULY 18 CREEK MOUTH; Haul With 1/4" Mesh Seine
- 679 Killifish F. heteroclitus and F. majalis 1" - 5-3/4"
- 422 Silverside Menidia menidia 1-1/8" - 4-1/8"
- 341 Weakfish Cynoscion regalis 1" - 3"
- 9 Lizard Fish Synodus foetens 2-1/2"
- 5 Menhaden Brevoortia tyrannus 1-7/8" - 3"
- 2 Mullet Mugil cephalus 5-1/2"
- 2 Puffer Spheroides maculatus 7/8"
- 2 Fluke Paralichthys dentatus 6" & 13"
- 1 Sea Robin Prionotus sp. 4"
- 1 Sea Bass Centropristes striatus 5-1/4"

JULY 20 CREEK MOUTH; Haul with 1/4" Mesh Seine
- 29 Killifish F. heteroclitus and F. majalis 1-1/4" - 3-3/4"
- 21 Silverside Menidia menidia 1-5/8" - 3-3/4"
- 19 Menhaden Brevoortia tyrannus 2-1/2" - 3-1/4"
- 8 Weakfish Cynoscion regalis 1-1/4" - 2-7/8"
- 2 Sea Bass Centropristes striatus 4-3/8" - 5-1/2"

SEPTEMBER 14 CREEK MOUTH; Haul With 1/4" Mesh Seine

71	Killifish	F. heteroclitus and F. majalis	1-3/8" - 4-7/8"
55	Silverside	Menidia menidia	1-3/4" - 4-1/4"
6	Weakfish	Cynoscion regalis	2-1/8" - 3-1/8"
3	Mullet	Mugil cephalus	5-3/8" - 5-1/2"
1	Menhaden	Brevoortia tyrannus	4-1/4"
1	Fluke	Paralichthys dentatus	11-1/2"
1	Goby	species of Gobiidae not determined	1-5/8"

Fish regularly enter or leave the creek and ditch systems with daily tidal currents. Only during the higher tides are they able to enter and leave the pools. In periods of such high water, fish populations in pools fluctuate greatly. This was demonstrated during three consecutive days when fish in a certain pool were present, absent, and then relatively abundant.

Methods of Study

Preliminary seining of fish from ponds indicated that this method would not be practical in appraising DDT mortality. Many fish were killed in these operations, and, in addition, it appeared almost impossible to capture all the fish in the ponds. For these reasons, seining of ponds was abandoned as a principal procedure. Instead, studies of fish mortality were based on: (1) general observations of fish abundance and activity before and after sprayings, (2) counts made within screen barriers set in creek channels, and (3) the use of caged fish.

General Observations

Seventeen hours after the first spraying in the 1.6 area dead fish were strewn liberally over creek sides and bottoms. Many others were seen floating in the slow ebb current of the creek. Observations of ditches revealed numbers of dead fish and no live ones although some fish normally remain when there is sufficient water. Nearly complete mortality occurred in shallow tide pools while in deeper pools it was somewhat less. Small fish less than 1-1/2" long made up the majority of the kill although a number of larger individuals up to 3" in length also succumbed. Fundulus killifish proved to be the predominant victims everywhere. Gulls were observed scavenging on a large scale. By the third day after spraying the evidences of death had largely disappeared. Gulls had aided in cleaning out dead fish from the tide pools and waterways, and water currents undoubtedly had removed many of the floating carcasses from ditches and creeks. By the fifth day after spraying, not one dead fish could be seen anywhere in the area.

Results of the second spraying on the 1.6 area were similar to the first. Mortalities in pools appeared as great as previously but the effects in creeks and ditches seemed less. Again, by the fifth day after spraying, all evidence of dead fish had been removed.

On the day after the first spraying in the 0.8 area, small dead killifish were found in tide pools and some were noted in ditches. None could be seen in the large creek draining the area or along its banks. On the second day after spraying additional deaths in the tide pools were noted, and there was a beginning of mortality in the deeper pools. At the same time mortality in the ditches was evident but not heavy. Again no dead fish could be found along the creek bank. By the fifth day after spraying practically all evidences of fish mortality had disappeared, and no new deaths had taken place. The second spraying on this unit gave similar results. On the whole, the mortality in the 0.8 area was approximately half of that observed in the 1.6 area.

In the 0.4 area, not one dead fish could be found in the tide pools, ditches, or creeks on the second day after the first spraying. Searches made through the fourth day after spraying likewise showed no dead fish anywhere in the area. However, after the second spraying, light but widespread mortality and weakening of fish was evident. By the fourth day all such effects had disappeared. The difference in results of the first and second spraying may be due to the slightly greater dosage rate of the latter.

A thorough survey on part of the 0.2 area one day after the first spraying showed only a few dead fish. These were in the shallowest pools and consisted of Fundulus no more than one inch long. On the two succeeding days, no new deaths were discovered, nor were any fish noted in a weakened condition. Results of the second spraying were similar. A few dead fish were evident in the tide pools on the first day following application but none were seen in the creeks and ditches. On the second day, there were a few dead fish in the ditches and creeks as well as in the pools. By the fourth day all traces of mortality had disappeared.

Enclosed Channel-Section Studies

The same sets of creek and ditch screen barriers used in evaluating DDT damage to blue crabs (described under that section, page 15) also proved helpful in appraising the effects upon fish. However, this approach was applied only in the 0.4 and 0.2 areas and was limited to the second spraying.

The screen barrier in the upper part of each channel section was closed during early morning ebb tide of the day before spraying and the lower screen barrier was closed after the subsequent flood tide had progressed for about 3 hours. Following sprayings, dead fish in the enclosed channels were removed as found. When mortality had apparently ceased, the remaining live fish were recovered by poisoning with rotenone.

The findings in the 290-foot channel section on the 0.4 area were as follows:

Dead Fish	2432
Live Fish	410
Mortality	86%

Practically all the dead fish (Fundulus) measured less than 3 inches, while the surviving ones (also Fundulus) ranged from less than 2 inches to slightly more than 4 inches long.

In the 0.2 area mortality was very light. Only 3 dead fish were found in the 225-foot channel section between barriers the day after spraying and none additional were noted thereafter. Live fish were not counted since a hole that developed under the lower screen barrier on the fourth day after treatment made possible the escape of some.

Caged Fish

An attempt was made to appraise mortality by means of cages containing known numbers of fish. The cages measured 2 feet on each side and were covered with 1/4-inch hardware cloth. They were placed in ponds or creek channels prior to spraying. The procedure, as applied, proved unsatisfactory and did not give usable results. It appears probable, however, that with slight changes, the equipment and method may prove useful in future investigations. Experience in these preliminary studies indicated need for greater care in handling captive fish and showed the importance of having specimens sufficiently large to avoid confusion with small killifish able to enter through the wire mesh. Although the effects of spraying on fish populations were not determined satisfactorily by this method, there was evidence that killifish of the genus Cyprinodon survive DDT treatment better than do species of Fundulus.

EFFECTS OF SPRAYING ON INVERTEBRATES

Insects

The New Jersey Agricultural Experiment Station conducted insect mortality studies in connection with the first spray treatment and made special investigations on the effects upon mosquito larvae and pupae and upon greenhead flies. The results of this work are reported elsewhere.

Kinds

Nine orders of insects were represented in the sweepings and collections made on the salt marsh in September and October. Of these orders, only two, leafhoppers (Homoptera) and flies (Diptera), were abundant. Fairly common insects included true bugs (Hemiptera) and the wasp group (Hymenoptera). The grasshopper group (Orthoptera), lace-wing group (Neuroptera), beetles (Coleoptera), and butterflies and moths (Lepidoptera) were the other orders found in sweepings. Dragonflies (Odonata) were also present but were absent from the sweepings due to their swiftness of flight.

Methods of Study

Net sweepings were made before and after sprayings to determine DDT spraying effects upon the insect fauna of the salt marsh. Sweepings were accomplished with a standard insect collecting net 15 inches in diameter, 100 sweeps comprising a sample. Courses about 160 feet long, well away from the area boundaries, were marked off in all spray areas and in the check area. Two or more were placed in uniform portions of the tall-grass and short-grass habitats of an area. All subsequent sweepings were made along the same course or a short distance to one side where possible.

Net Sweepings

Sampling in the check area before the second spraying showed an average of 804 insects per 100 sweeps in the short grass and 576 in the tall grass. These preliminary samplings also indicated that the check area was not fully comparable to untreated portions of the 1.6 and 0.8 areas, the test plots having populations 1/3 to 2/3 less on the average than the check. For this reason most of the comparisons made in the following discussion are based on pre- and post-spray figures obtained within the same area.

Effects of first spraying.--Early September insect sweepings of the 1.6 and 0.8 areas revealed the following population decreases in sprayed portions when compared to unsprayed portions:

1.6 area: 80% decrease in short grass
42% decrease in tall grass

0.8 area: 59% decrease in short grass
21% decrease in tall grass

These results indicate a 21% greater reduction of insects by the 1.6 than by the 0.8 lb. per acre application and show about 38% greater mortality in the short grass than in the tall grass.

Additional sweepings in late September and early October of these same areas treated only in August revealed still further declines in the insect populations of the two higher dosage areas. However, the lower dosage areas showed increases over pre-spray counts indicating that residual effects of spraying at these rates of application were of less duration than at the higher dosage rates and that population recovery had occurred by this time.

Effects of second spraying.— Sweepings were made before and after this spraying in portions of the 1.6 and 0.8 areas that had not been treated in August. The populations in these units showed greater reductions following spraying than had occurred after the first application. However, similar but smaller decreases were observed in the check area during the same period and suggest that the lower populations after spraying were in part due to a usual seasonal decline.

Insect populations decreased still more on those portions of all areas that were sprayed twice. As after the first treatment, an indirect relationship existed between numbers of insects and dosage. Populations in long grass habitats showed greater survival than in short grass.

Blue Crabs

Ecology

The common blue crab, Callinectes sapidus, frequents creeks, ditches and ponds in salt marshes. Much of its population, particularly the medium and large-sized individuals, moves outward from the marsh into deeper water with ebbing tides and returns with flood tides. Saltmarsh ponds are likely to be inhabited by smaller individuals which do not migrate with the tides. The blue crab is largely aquatic but may stay on moist banks for extended periods. Unlike the fiddler, it does not inhabit burrows. Individuals that remain in ditches or creeks temporarily drained by the tide are likely to bury themselves in the mud or hide under other cover.

Methods of Study

Evidence of DDT spray effects upon blue crabs was obtained by two procedures: (1) General observations consisting of visual estimates of effects upon populations and (2) studies in creek and ditch sections enclosed by screen barriers.

General Observations

Observations made on the 1.6 area one day after the first spraying seemed to indicate a nearly complete kill of the crabs present at spraying. The few crabs that were not dead appeared feeble. There was evidence that new crabs entering the area continued to be killed. Live crabs were not seen in any numbers until two weeks after spraying. By the time of the September spraying, active crabs were again present in the 1.6 and 0.8 areas but not in numbers as great as prior to the first treatment. The second spraying also caused very heavy mortality within 24 hours. The total number found dead was only about half that encountered after the first spraying and the individuals appeared to average smaller in size. A few live crabs were found in heavy vegetation.

In general, the results on the 0.8 area were similar to those on the 1.6 area though the mortality, 16 hours after both the first and second treatments, did not appear to be as sudden or as complete. On this area, however, a larger proportion of individuals was noted with tremors. Two and a half days after the first spraying there were a few more live crabs than had been observed in the 1.6 area.

The 0.4 dosage caused much less mortality than the two higher ones. The first spraying resulted in only a slight kill, but dead crabs were decidedly more numerous after the second treatment. As in the case of fish and fiddler crabs this increase in mortality may be attributed to the higher application during the second spraying. The toxic effects of DDT did not appear to last over six days.

Both the first and second sprayings in the 0.2 area resulted in only light mortality. A few dead crabs and some with tremors were found.

Enclosed Channel-Section Studies

After the first spraying and prior to the second one an additional means of determining blue crab mortality was devised. It involved the use of sets of screen barriers placed across certain creek or ditch channels. Each barrier consisted of a board fence with removable screens of $\frac{1}{4}$-inch hardware cloth in the central section (see Fig. 2). Measured lengths of creek or ditch channels were thus enclosed by barriers in each of the four study areas.

Since the screen-covered portion of the barrier was constructed like a sluice gate, it could be opened at low water, closed during the following high tide, and re-opened during low tide after dead crabs had been counted and removed. This arrangement, enabling "outside" crabs to come into the enclosure during high tide and deterring their escape with ebb tide, was employed in the units that received heavy dosages. In the other two units (0.4 and 0.2 areas), screen barriers at both ends of the channels were shut the day before spraying and were not re-opened until the end of the experiment. Observations on mortalities within the channel enclosures in the study areas are summarized below.

The channel enclosed in the 1.6 area was part of a large ditch about 4 feet deep and varying from 2 to 4 feet in width. Since the ditch was a dead-end one, only a single barrier was required. This barrier shut off about 500 linear feet of the ditch. After the spraying, no live crabs were seen during three visits to the enclosure. Dead crabs were found as follows:

Days After Spraying:	1	5	10
Dead Crabs Found and Removed:	46	27	12

In the 0.8 area about 800 linear feet of ditches approximately 3 feet wide and averaging 3 feet in depth were enclosed by three screen barriers, one across each of two upper branches and another across the main, lower part of the ditch. Only the lower screen barrier was opened and closed with the tides. Again no live crabs were found in three visits following the spraying. Dead crabs found were as follows:

Days Following Spraying:	2	5	10
Dead Crabs Found and Removed:	98	28	16

Another enclosure in this study area included approximately 4,300 linear feet of winding creek and tributary ditches. The creek was about 14 feet wide and 4 feet deep. Following the spraying, only one live crab was seen--10 days after the treatment. Dead crabs were noted as follows:

Days Following Spraying:	2	5	10
Dead Crabs Found and Removed:	269	122	34

The enclosure in the 0.4 area embraced 290 linear feet of a creek averaging about 4 feet wide and 3 feet deep. Observations were made daily or every other day until there was no further evidence of mortality--18 days

after the spraying. Of the 211 crabs found in the enclosure during this period, 192 (91%) were dead. Of the 19 (9%) that survived, 7 were very active while the other 12 were sluggish.

A creek channel 225 feet long and averaging about 3½ feet wide and 3 feet deep was enclosed in the 0.2 area. As in the 0.4 area, observations were made daily or on alternate days until there was no further evidence of mortality. However, the significance of results in this enclosure was seriously reduced by a break in the down-stream barrier on the fourth day after spraying. This was repaired immediately but undoubtedly some crabs had escaped. The total number recovered within the 20-day period after spraying was 30, of which 19 (63%) were dead. The 11 live crabs that were found appeared to be healthy and active.

Fiddler Crabs

Ecology

The saltmarsh fiddler crab, Uca pugnax, is primarily a species of muddy soil and saline waters. It is usually found in the zone between high and low tide. Within the salt marsh, it occurs commonly on mud banks of creeks and ditches, on sandy-mud shores of bays and river mouths, on sods of sparse marsh grass, and on moist, bare flats.

Most male and female fiddlers over $\frac{1}{4}$ inch in width dig burrows which serve as their homes. Males are especially territorial and usually confine their activities to the immediate vicinity of their burrow entrances, but females and young tend to wander. However, such wanderings are generally limited to distances less than 15 feet. The burrow serves as a refuge during periods of overcast skies or darkness, at high tide, or in times of danger. The greatest numbers of crabs are likely to be observed on clear, sunny days during ebb tide.

Methods of Study

Assessing the damage of DDT sprayings to marsh fiddler crabs was complicated by several factors. Some of the difficulties were evident at the study's outset but others became more apparent during its progress. From the beginning it was clear that population counts would not be easy. Droves of feeding fiddlers on mud banks or elsewhere disappeared quickly into their burrows when approached. Furthermore, counts attempted from a distance omitted many of the smaller individuals.

Four principal methods were employed in trying to determine harm to fiddler crab populations from DDT sprayings. These were: (1) General observations; (2) enclosures; (3) closing burrows; and (4) soil-surface sampling.

General Observations

The first spraying on the 1.6 area was made during high tide. This factor probably reduced greatly the extent to which fiddlers came into direct contact with DDT spray. Subsequent opportunity for DDT contact was further reduced by unfavorable weather; yet on the first and second day after spraying there was evidence of some mortality. Recent kills were found and there were increased numbers of claws from many others which had been eaten by birds.

The second spraying caused considerable mortality. Even five days after the application many dead fiddlers were found and many in the deeper creek channels were dying.

As in the case of the 1.6 dosage, the 0.8 treatment caused a moderate loss, though the evidence of effects appeared somewhat later. Both the first and second sprayings resulted in widespread kills. In

addition, many crabs were found in a sluggish condition. Mortality was apparently more severe in flat areas than on well drained banks. Deaths continued to occur for at least ten days after the spraying.

A light but widespread kill occurred on the 0.4 area, with a somewhat greater mortality after the second spraying than after the first. This is in agreement with the higher mortality of fish and blue crabs occurring in this plot at the same time. However, the severity of kill seemed appreciably less in this plot than in the case of the heavier dosage areas. A minimum of 30 dead crabs was found along 290 feet of a creek section after the second spraying.

There was slight and inconclusive evidence of mortality on the 0.2 area following both sprayings. The few dead crabs found were assumed to have been killed by DDT.

Enclosures

This method of testing DDT effects on fiddler crab populations made use of a square frame of sheet metal, 22 inches on a side and 12 inches deep, sunk 8-9" into the ground. Though box-like in form, it had no bottom. In the fiddler banks where this frame was used, crab burrows did not extend more than 10 inches deep. A covering of $\frac{1}{4}$ inch hardware cloth was placed over the top to prevent crabs from escaping during high water and to preclude depredation by birds.

Preliminary tests involving the removal of all crabs within an enclosure demonstrated that fiddlers were usually more numerous than their burrows. The results of four samplings are given below and indicate that, in these instances, the number of fiddlers averaged half again the number of holes.

Sample No.	No. of Holes	No. of Crabs	Ratio of Holes to Crabs
1	28	76	1 - 2.7
2	42	80	1 - 1.9
3	94	117	1 - 1.2
4	48	61	1 - 1.3

In sampling the effects of DDT sprayings, one or more pairs of frames were placed in each area. They were set side by side before the spraying in places where comparable conditions of habitat and crab population existed. About a day before the spray was applied, one frame of each pair was covered with waterproof paper to protect the crabs in that enclosure from direct contact with DDT and to serve as a partial check. Burrows, classified as small, medium, and large, were counted before and after spraying and the number of active crabs of different sizes seen within the enclosures after spraying was noted. Record was made of any dead specimens removed.

Limitations of time and staff, as well as interference by adverse weather, prevented a full utilization of this method during both sprayings. Observations on enclosures during the second spraying were inconclusive,

but those following the first spraying gave rather clear-cut confirmation of "general observations." In brief, there was evidence that the two high dosages (1.6 and 0.8) caused severe mortality, particularly of "tick-size" specimens, while the toll from the lighter dosages was less. A summary of enclosure findings following the first spray application is given below:

1.6 dosage -- nearly complete mortality of tick-sized specimens; fairly heavy loss of large and medium-sized crabs.

0.8 dosage -- 50-75% mortality of tick-size; less than 50% mortality of medium and large crabs.

0.4 dosage -- some mortality (less than 50%) among various size classes.

0.2 dosage -- about 25% kill in various size classes.

Closing Burrows

This technique consisted in counting the holes in a colony, covering them with a thin smear of mud and later noting the number of re-opened burrows. By this means it was thought that an index of active fiddlers might be obtained since each re-opened hole was assumed to represent at least one live crab. Contrary to expectations, this procedure did not confirm the observations obtained by the other methods. Indeed, there were some increases as well as decreases in the number of open burrows following sprayings. The reasons for such increases in areas of higher dosage application are not apparent. Because of conflicting results, the data are not presented.

Soil-Surface Sampling

Though the soil-surface sampling procedure (see page 20) was designed and used primarily for studying populations of other small invertebrates in grassy areas, it also gave some information on numbers of fiddler crabs--usually small-sized ones--before and after spraying. Generally the number of fiddlers found in each foot-square sampling of the surface was too limited for the method to be significant by itself.

In areas subject to the 1.6 and 0.8 pounds of DDT per acre, samplings taken two weeks after the first spraying showed a decrease of about 22% in live crabs compared to pre-spray samplings. At the same time, the low dosage units showed no appreciable change in populations after spraying. The second application resulted in a similar though smaller decrease in the high dosage areas. In contrast, no dead crabs were found in pre-spray samples of treated areas or in any check area samples.

Other Invertebrates

A principal means of studying populations of various small invertebrates was a method here designated as soil-surface sampling. The equipment used consisted of a foot-square frame with sides 6 inches high and a flanged top. This was placed on the ground and forced firmly into the sod an inch or so to prevent organisms from escaping or entering underneath. Within the frame, the grass was cut to permit greater observation of the soil surface and facilitate capture of organisms. These were picked up with forceps and preserved for future analysis. Note was made of all organisms which eluded capture. Soil-surface samplings were taken at an average of 7 stations in all sprayed areas, as well as in the check area prior to the initial spraying, and were repeated once or several times after each treatment. Uniformity of topography, drainage, and vegetational cover were considered in selection of sites for the original samples. Succeeding samples were taken a short distance away, usually within several feet of the first samples.

In addition to soil-surface sampling, general observations and, in some instances, net sweepings were helpful in appraising population changes among small invertebrates.

Spiders

Despite subjection to periodic flooding by the tides, spiders are common inhabitants of the salt marshes. They serve in the role of predators upon insects and other small invertebrates and in turn are a source of food for larger organisms. Two of the most common and most conspicuous spiders included the wolf spider which builds no web but pursues its prey and the orb weaver which constructs a web. Investigations on the response of spiders to DDT applications were made by (1) general observations, (2) marking of web locations, (3) soil-surface samplings, and (4) net sweepings.

General observations revealed dead or dying individuals of the wolf spider within 24 hours after both sprayings in all areas, but particularly in the two of higher dosages. Most of those observed were on the surface of ponds or mud flats where they had strayed while affected by DDT. A few orb weavers likewise were noted dead in their webs on the day after spraying.

Before the second spraying, active webs located in conspicuous sites were marked in the check area and in previously unsprayed portions of the 1.6 and 0.8 areas. These were observed for several days prior to treatment. On the fourth day after spraying no live occupants were noted in the sprayed areas while many of the webs in the check area were still in use.

Soil-surface samplings before and after spraying revealed reductions in the number of ground-inhabiting spiders in all areas following treatment. These decreases ranged generally between 50-90% and were greatest in the areas of high dosage. At the same time, sampling in the check area

showed the number of spiders there to be greater than when the original pre-spray samples were taken. Portions of the 1.6 and 0.8 areas treated only in August showed little or no recovery of populations by the end of September.

Net sweepings gave information on the effects of the second spraying on web builders and other species of spiders inhabiting the strata above the soil surface. Decreases in population after spraying were noted in almost all cases and, as indicated by the soil-surface samplings, the greater decreases were observed at the higher dosage rates. However, the populations in the check area also showed a decrease. In early September, populations on unsprayed portions of the 1.6 and 0.8 areas were about 2.5 to 3 times as great as populations on sprayed portions.

Red Mites

Red mites are common on the soil surface and vegetation of the salt marsh. Contrasted to the decline in spider populations after spraying, there was a general increase in numbers of red mites as revealed by soil-surface samples. A comparable population rise also occurred in the check area, possibly due to a seasonal increase. The largest increases occurred after the second spraying in the area of highest dosage. Similar indications were obtained from net sweepings. These increases in red mite populations following DDT spraying appear to correspond to those observed by other investigators elsewhere.

Marsh Flea, Orchestia grillus

The marsh flea is an amphipod and a close relative of the better-known beach flea (O. platensis). It occurs on or beneath the soil surface, being most common in protected places at or above the high-tide zone. Fish, birds, and other vertebrates feed upon it, and it also has value as a scavenger.

Soil-surface sampling proved ineffective in measuring populations of these elusive organisms. Nevertheless, the effects of DDT spray appeared clear-cut. Though an average of two individual marsh fleas (highest single count 16) were seen in foot-square samples prior to the first spraying, no live ones were found by this method on any of the areas after treatment. This held true for 11 weeks, the period during which observations were made. At the same time, original numbers were maintained or increased on the check area.

Saltmarsh Sowbug, Philoscia sp.

As in the case of marsh fleas, saltmarsh sowbugs were found to be too elusive to count readily by the soil-surface sampling method. In general they were common, an average of 1.6 individuals (highest single count 49) being found in a foot-square area prior to spraying. General observations showed that DDT was very destructive to these isopods. Live sowbugs were noted in only two instances after an area had been treated: one individual in the 0.8 area 24 days after spraying and two in the 0.2

area 40 days after treatment. Samplings in the check area revealed little change throughout this period.

Ribbed Mussel, Volsella demissa

This is probably the commonest mussel along the East Coast. It is characteristic of the intertidal zone where it occurs embedded in the marsh sod or in comparatively firm mud banks of ditches and creeks, as well as on pilings and other objects in the water.

Information on populations of this mussel was derived primarily from soil-surface samplings. However, a foot-square sample proved inadequate for statistical purposes. Counts from all areas before spraying averaged only 2.8 mussels per sample and varied from 0.4 to 7.0, the variation being due largely to the colonial habit of this animal. Some individuals may have been overlooked by reason of their protective coloration and limited projection above the soil surface. It appeared that DDT treatments had little effect on mussels, since the average number of live individuals in samplings on all areas after the second spray was 3.1, an average increase of 0.3 mussel per sample.

Saltmarsh Snail, Melampus lineatus

This is the commonest snail in the saltmarsh habitat. Its greatest abundance occurs in the sod and grass at the upper levels of the tidal range. Black ducks use it as food--sometimes in quantity. It is eaten by the clapper rail to a lesser extent.

Soil-surface sampling was the principal method used in determining the effects of DDT spraying on these snails since general observations revealed no noticeable population differences. As a rule, there was an increase in the number of live snails per foot-square sample in all areas after spraying. A few decreases were noted on several of the treated areas, principally in samplings made after the second spray application. The check area showed an increase at this time. Volumetric measures of all collections gave figures that corresponded closely to the increases in numbers. Furthermore, calculations of the average size of an individual snail at the time of each sampling revealed a progressive increase in all but the 1.6 area as the season advanced. This highest dosage plot showed a general decrease in average snail size due to large increases in numbers of small snails.

SUMMARY

Cooperative studies were conducted on a New Jersey salt marsh in 1949 to ascertain the effects upon wildlife of DDT sprayings comparable to those applied for control of mosquito larvae. Four study areas were established and treated by plane at rates of 1.6, 0.8, 0.4 and 0.2 pounds of DDT per acre respectively. Sprayings were made at two periods: August 17-19 and September 15-16. The study plots were 90 to 100 acres each except for the one of highest dosage (1.6 lb. per acre) which was only 50 acres. A check area was also established. Population appraisals were made before and after spraying to determine the extent of mortality, if any. In brief, direct harmful effects upon birds were not evident but mortalities of fish and of organisms important as food sources for wildlife were commonly heavy, especially where the two higher dosages were applied. A summation of effects on each of the animal groups studied follows:

Birds

No harmful results to birds were noted except that populations of swallows declined in the areas receiving the heaviest dosages. Presumably these decreases represented movements away from the treated plots. Gulls flocked into areas where quantities of DDT-killed fish and crabs were available. However, no evident harm resulted to these birds nor to clapper rails feeding on dead fiddler crabs. Land birds, such as the long-billed marsh wrens, sharp-tailed sparrows, and seaside sparrows, successfully reared their young in sprayed areas and apparently found sufficient food.

Fishes

Mortality to fishes appeared to depend largely upon the DDT dosage. The 1.6 pounds per acre application caused a nearly complete destruction of killifish in shallow ponds but survival was greater in deeper ones. Considerable mortality occurred in creeks and ditches but here it was far from complete. The kill in the 0.8 area was judged to be half of that in the 1.6 area. The other two areas sustained only light mortality as determined by general observations. However, an 86% mortality was observed in an enclosed creek-section study under a 0.4 dosage, indicating heavy losses to fish that are confined within a sprayed area. As a rule, small fish proved to be more susceptible than large fish and Cyprinodon killifish were able to withstand DDT applications better than Fundulus killifish.

Insects

Insects of nine orders frequenting the saltmarsh habitat were severely reduced in numbers by the sprayings, the destruction being generally in proportion to the dosage applied. Three weeks after the first spraying, in areas where 1.6 and 0.8 pounds per acre of DDT were used, insect populations varied from one-fifth to four-fifths less than formerly. Six to seven weeks later, populations in the 1.6 and 0.8 areas showed still

further decreases but in the two lower dosage areas residual effects were no longer of importance. It was evident that mortality of insects in tall grass growths was only about half of that in short grass.

Blue Crabs

Mortality to the blue crabs present at spraying as well as to those entering the area with subsequent tides was apparently very heavy or nearly complete at the 1.6 dosage application. The 0.8 application caused a nearly equal kill. In these two higher dosage areas, toxicity to crabs was evident for ten days to two weeks following spraying. Losses were lighter under applications of 0.4 and 0.2 pounds per acre. However, crabs confined to a creek channel in the 0.4 area suffered a 91% mortality.

Fiddler Crabs

Saltmarsh fiddler crabs, though apparently not as susceptible as blue crabs, suffered fairly heavy mortality from the higher dosages and moderate or light kills from the 0.4 and 0.2 dosages. The heaviest losses were among the small, tick-size individuals. Greater mortality was noted in flats than on well drained banks. Mortality occurred for at least ten days after spraying at the high dosage levels.

Other Invertebrates

Populations of ground-inhabiting and web-building spiders suffered greatly from DDT sprayings and showed little sign of recovery by the end of the summer. Mites, on the contrary, were generally more numerous after spraying and showed the largest gains on the area of highest dosage. Saltmarsh amphipods and sowbugs were apparently almost completely eliminated at each of the four dosage rates. In contrast to this, the ribbed mussel showed little or no effect, and the saltmarsh snail actually increased in numbers and size in most study areas after DDT treatment.

RECOMMENDATIONS

Since the investigations covered in this report were intended to be preliminary to others in the following year or years, a statement of recommendations will be reserved until studies are completed and until there has been final interpretation of all findings.

Interior--Duplicating Section, Washington, D. C. 96093

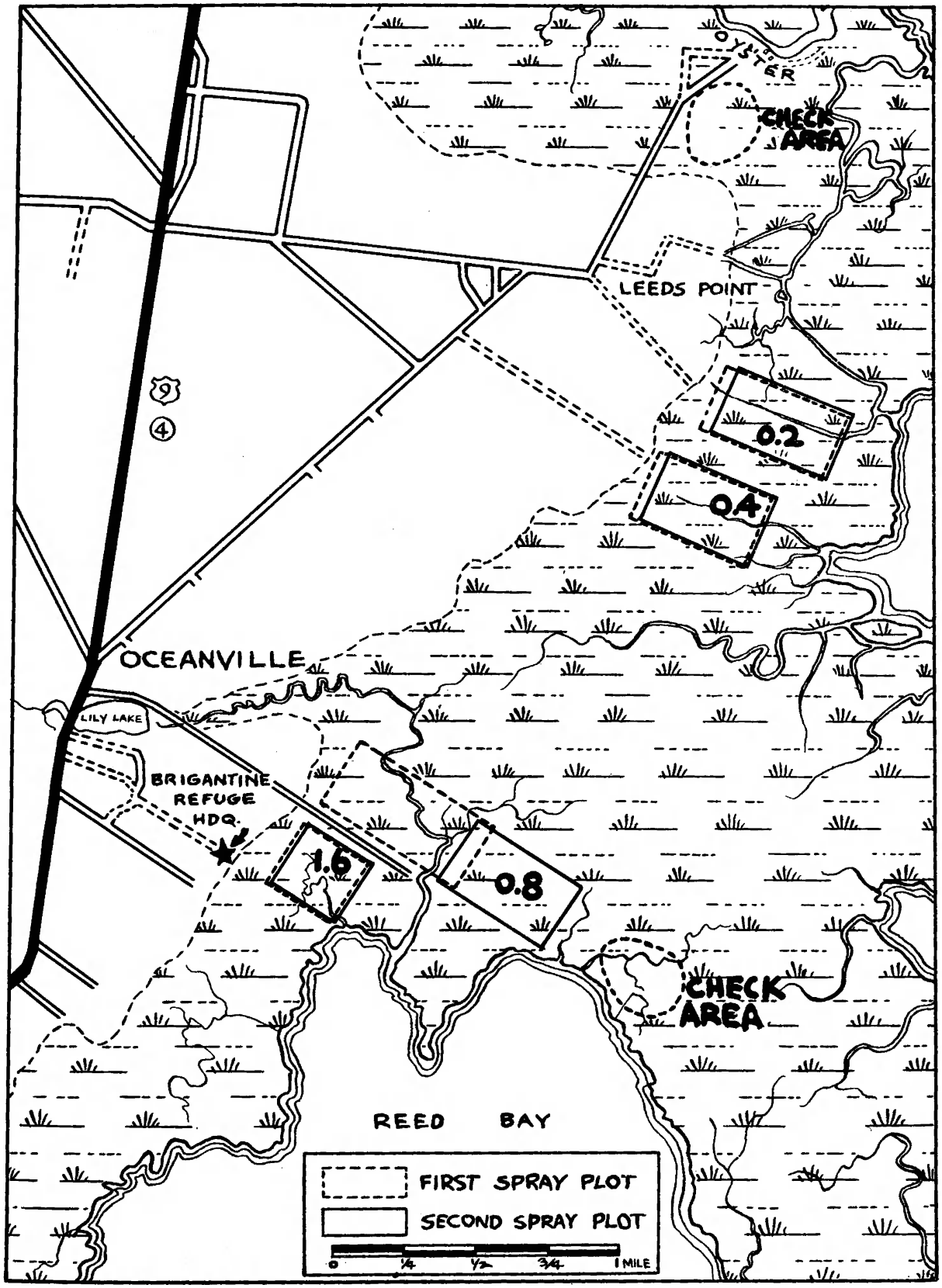

Figure 1.- Sketch showing location of DDT-treated and untreated study plots at Brigantine National Wildlife Refuge, Oceanville, New Jersey.

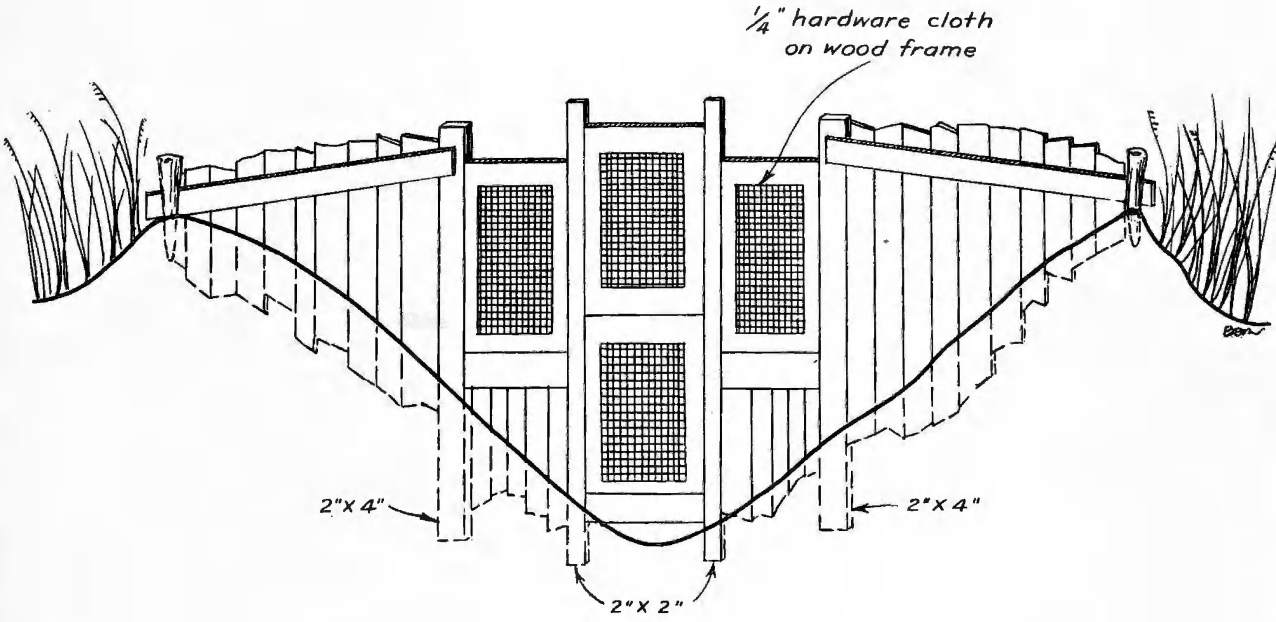

FIGURE 2.- A BARRIER USED TO ENCLOSE BLUE CRABS AND FISH IN TIDAL CHANNELS